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Development of a Bottom-up Technology Assessment Model for Assessing the Low Carbon Energy Scenarios in the Urban System

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Abstract

This paper explores an approach based on a systematic-integrated modeling framework which helps to investigate the optimal behavior of an urban energy system. The model allows us to: 1) analyze the impacts of various demographic scenarios, 2) test and evaluate different policy measures for deploying patterns of efficient use of energy resources and emissions mitigation in the system and 3) test technological and system level solutions such as centralized versus decentralized energy supply networks. A highly resolved optimization technique using mathematical programming is applied to identify the cost-effective measures for achieving specific energy and emissions reduction-targets. The model then is applied to identify the optimal energy flow from available energy resources (Fossil, Renewable and external sources) to the end-user level in selected cities of Asia.

Keywords: Asian cities; energy systems; low carbon society, optimization model.

1. Introduction

Analysis of multi-dimensional interactions of flow of energy in the urban energy system is a complex task that necessitates the development and utilization of analytical tools. Development of analytical tools with high complexity is usually based on conclusions of many concepts and theories from different scientific disciplines. Technology assessment and efficiency evaluation of the urban energy system have been pursued with the help of

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analytical tools that have been developed and implemented in the last decades [1-4]. Many of the available analytical tools are based on the heuristics and experimental data. But there has been little effort on concluding the theoretical background of analysis and developing respective energy models according to the optimal behavior of the system.

In this paper, an urban energy system is supposed to be organized in the form of a firm and appears in the market that oriented towards establishing an effective energy system to improve its overall resource efficiency which may be identified as delivering a certain level of urban quality (i.e. Demand for transport activity, space heating, lighting, air conditioning, etc.) with minimum total cost of the system. To this end, an optimization model founded on the microeconomic principles has been developed using the technique of mathematical programming.

Nomenclature

Z	Total Cost
k	Capital
m	Operation cost
e	Externalities
t	time
u	level of utility (i.e. electricity, mobility, heating, etc.)

2. Conceptual design of the model

In this research, the microeconomic principles have been utilized to develop a model that would represent the behavior of an urban energy system in a market with a perfect competition [5]. The local government as a decision maker in this market strives for maximum satisfaction (or utility) of delivering certain energy service to the end-users such as providing required electricity at the end-user level. The utility or satisfaction is a function of a broad range of parameters such as quality of the service, comfort, accessibility, environment, costs and time. Maximizing utility is subject to certain constraints due to the availability of resources. The resources are time, capital for obtaining a quality service, availability of reliable system environment and income. The solution of such a mathematical model would be possible if the utility function could be identified and formulated explicitly based on both supplier (local government) and consumers (end-users) viewpoints (Fig. 1). An alternative methodology has been developed which may be categorized as a direct solution of the model. Although the solution of the model based on the maximization of the utility of delivering energy services would be hardly possible due to difficulty in obtaining an explicit formulation of the utility function, one may make an effort of solving the dual of the primary model. The dual formulation of the primary model would achieve the optimal utility with minimum total costs, which would direct capital and operation costs.

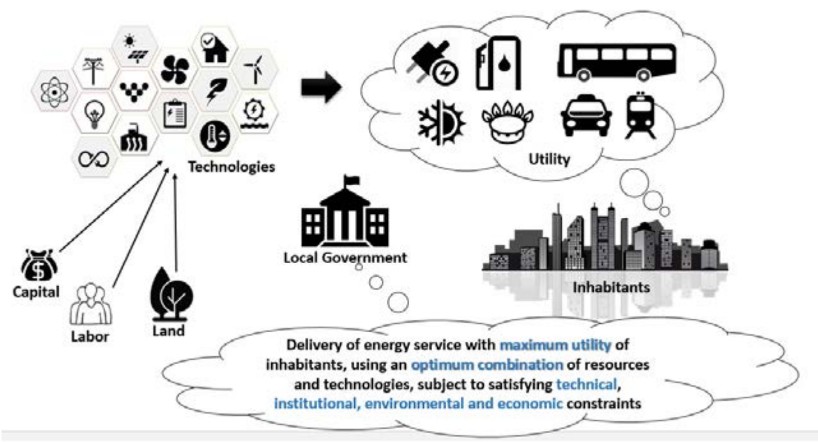

Fig. 1. Applying microeconomics principles to the urban energy ssystem

In other words, one may describe the dual of the primary model according to the formulation in Eq. (1)- (5):

$$Minimum \quad Z = C(k, m, e, t) \tag{1}$$

Subject to:

$$f(k, m, e, t) \geq u^{*} \tag{2}$$
$$m = g(k) \tag{3}$$
$$e = h(t) \tag{4}$$
$$k \geq 0, \ f \geq 0, \ t \geq 0 \tag{5}$$

The variables *k*, and *t* are capital, and time allocated for the delivering energy services to the end-users respectively. The variables *m* and *e* are operation costs and other externalities. The above model indicates that the total costs of achieving the optimal utility, *u**, is minimized. The problem with this model would be the quantification of optimal points of utility, i.e. *u**, and identification of the function that represents the total costs (*C*) and delivering of energy services (*f*) and other functions that are expressed as *g* and *h* in the above model.

A proxy to the above model has been developed which is founded on the following assumptions:

a. It is assumed that the total time would be fixed (i.e. 2015, 2020,… 2030)
b. It is assumed that the end-user would achieve a certain energy service which is a measurable unit (i.e. kWh)
c. It is assumed that the city profile and the surrounding condition (i.e. geographical location and ambient conditions) are given.
d. It is assumed that achievement of a certain energy service in a given time in a given case (i.e. for a city and surrounding condition) would represent the optimal utility.
e. Changes of behaviour and the costs of the system in a given time horizon are considered as the determining factors. Therefore, changes in the energy mix through deploying clean and highly efficient conversion technologies on the supply side and energy efficiency plans on the demand side are discussed as the determining factors.

The development of dual of the primary model has been based on the above assumptions. Then attempt has been made to identify the functions in the constraints of the dual model. This set of simultaneous constraints is formulated through the segregation of the total system into subsystems of energy conversion and transformation (Fig. 2). The overall structure of the modeling framework is depicted in Fig. 3.

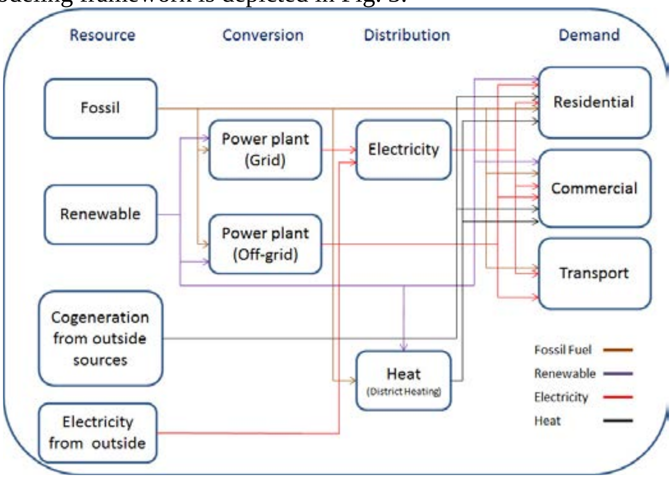

Fig. 2. Reference Urban Energy System

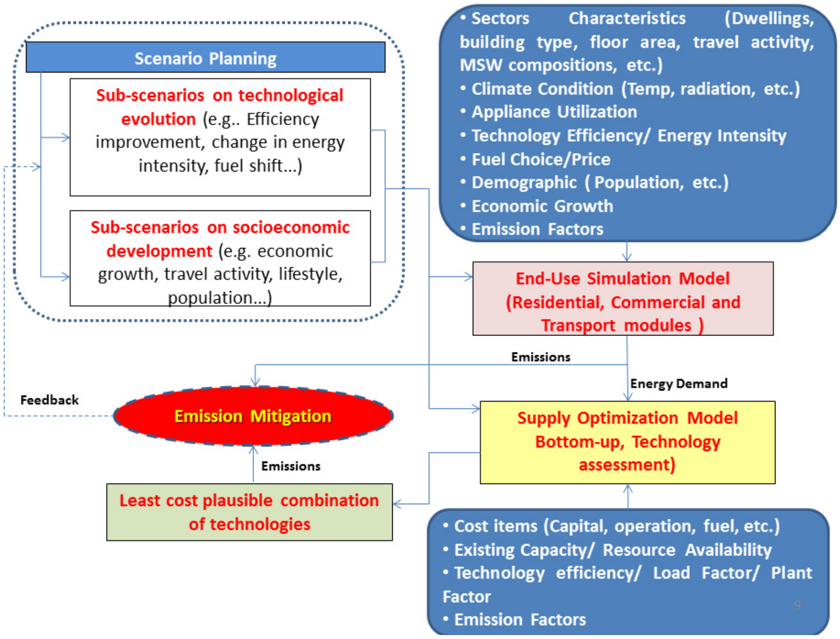

Fig. 3. Overall structure of modeling framework

3. Results and discussion

The model which has been developed is initially tested using real data to analyze the electrical power crisis in the city of Delhi as a specific case study. The city's end-user level is subdivided into different sectors (Residential, Commercial and transport) and specific consumptions are assigned to those sectors to assess their energy demand. The energy demand, then broken down per energy carriers of each end-user. The activity levels are estimated on the basis of the dwellings size and mode, available floor area in the commercial sector and total annual passenger kilometer in the transportation sector. In Delhi, domestic (Residential & Commercial) customers dominate the electricity consumption profile not only in terms of numbers but also in terms of load and consumption. Fig. 4 shows the electricity consumption of different sectors [6].

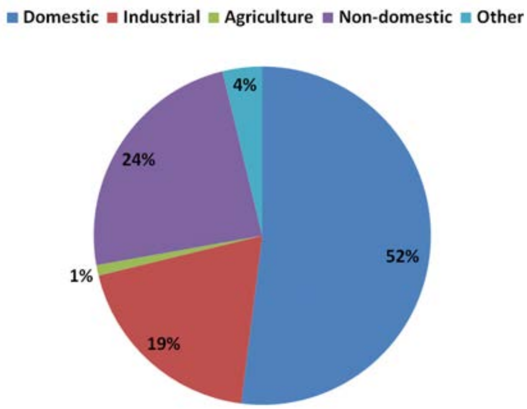

Fig. 4. Delhi sector-wise electricity consumption and power supply/demand position of the city of Delhi during the year 2012-13

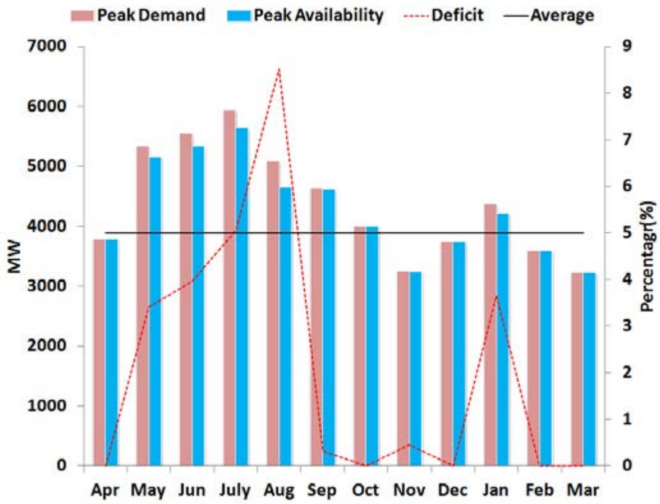

Fig 5. The average gap between electricity demand and supply

Based on the data of sectoral uses in the domestic area, combined with the maximum power made available from existing capacity, the average gap between electricity demand and supply is estimated about 0.623 TWh/yr per annum (Fig. 5). Given the existing condition, the model is used to explore the optimum (cost efficient) scenario to reduce the growth rate of electricity demand through adopting more efficient technologies in the domestic sector as well as efficient use of existing capacities or building-up new capacities in the resource level.

The results show the saving at the end-user level would be expected about 0.221 TWh/yr per annum, which could be achieved through improving lighting efficiency and air conditioning performance and also introducing about 0.201 TWh/yr of small-and medium-sized rooftop PV in certain categories of building. Beside this, generating approximately 46 MW electricity from municipal solid waste could enable a sufficient surplus for the power supply sector to meet the city's electricity demand (Fig. 6).

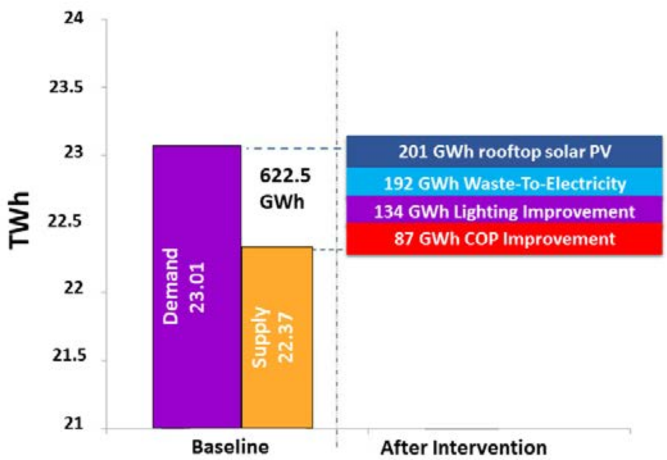

Fig. 6. Optimal results for electricity deficiency in Delhi and Potential reduction and abatement cost of GHG emissions in optimal electricity sector scenario

Promoting the optimal scenario could contribute to a considerable amount of GHG emissions reduction in the near future. The results show that, emissions mitigation accounted for 540 kt/yr of GHG emissions (CO_2-eq) by promoting the EEE and shifting from fossil energy to alternative energy in 2030. The cumulative potential reduction of GHG emissions between 2012 to 2030 is estimated about 5.9 million tons.

4. Conclusion

This paper has explored the use of an integrated-systematic modeling approach for the optimization of energy flow in the urban energy system. The key feature of the modeling approach we developed here is that it can be used to outline a planned reduction target along different dimensions while at the same time retaining the link between supply and demand vectors. The model was used to analyze the electricity crisis in the city of Delhi. The results of optimal scenario showed that the gap between supply and demand can be bridged only with structural reforms in the energy sector. These reforms will however take time to be implemented considering the numerous challenges involved. The implementation of the optimal scenario showed that the power crisis in the city of Delhi should be considered as a function of both supply and demand. Adding installed generation capacity alone will not solve the power crisis in this big city. Efforts need to be made on the demand side as well, even though demand-side solutions cannot replace supply augmentation in satisfying Delhi’s electricity demand. Consequently, the energy end-use efficiency and investment in renewable energy are immediate opportunities for restraining electricity deficiency in Delhi. It has been observed that a successful implementation of the proposed scheme can help the city of Delhi to free from load shedding. The validation study showed that this modeling framework is usable in practice as local governments and policy makers can generate realistic solutions for a wide variety of energy system problems at the urban level.

Acknowledgments

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